

# REPORT DOCUMENTATION PAGE

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14. ABSTRACT  The investigators have undertaken several efforts underlying the enhancement of the performance of III-nitride and related wurtzite quantum-dot-based optoelectronic devices. These include: carrier scattering by optical phonons; spontaneous polarization in wurtzites; the use of colloidal quantum dots as optoelectronic elements; strain- and confinement-induced shifts in the phonon frequencies in GaN quantum dots; two-phonon processes in photon absorption; phonon effects on carrier transport in nanowires, including wurtzite-based nanowires; and the design of photodetectors using wurtzite-based quantum dots and initial efforts on self-assembly of quantum dots into networks for optoelectronic applications. Eighteen refereed publication (with more in press) and resulted from this program as well as twenty-seven presentations, including seven invited presentations, have resulted from this program to date.					
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# "III-nitride and Related Würtzite Quantum-dot-based Optoelectronic Devices with Enhanced Performance"

## (1) Introduction

The investigators have undertaken several efforts underlying the enhancement of the performance of III-nitride and related würtzite quantum-dot-based optoelectronic devices. These include: carrier scattering by optical phonons; spontaneous polarization in würtzites; the use of colloidal quantum dots as optoelectronic elements; strain- and confinement-induced shifts in the phonon frequencies in GaN quantum dots; two-phonon processes in photon absorption; phonon effects on carrier transport in nanowires, including würtzite-based nanowires; and the design of photodetectors using würtzite-based quantum dots and initial efforts on self-assembly of quantum dots into networks for optoelectronic applications. Eighteen refereed publication (with more in press) and resulted from this program as well as twenty-seven presentations, including seven invited presentations, have resulted from this program to date.

## (2) List of Appendixes --- N/A

## (3) Statement of Problem Studied

The problem addressed in this AFOSR effort on high-performance III-nitride quantum-dot-based devices is to design and characterize optically III-nitride laser heterostructures through the application of the quantum-engineering techniques. The investigators studies mechanisms, phenomena, and interactions --- strain-induced shifts in the phonon frequencies in GaN quantum dots, confinement-induced shifts in the phonon frequencies in GaN quantum dots, carrier transport in heterostructure lasers, spontaneous-polarization effects in III-nitride quantum dots, radiation absorption due to two-phonon effects --- having potential for enhancing the performance III-nitride and related würtzite quantum-dot-based optoelectronic devices.

## (4) Summary of Most Important Results

The most important results obtained during this period of this effort include: electrical and optical studies of components of devices and systems of III-nitride and related würtzite quantum-dot-based optoelectronic devices; electronic and optical properties of quantum dots in ensembles; models of heterostructure-based and nanowire-based devices; models and measurements of strain-induced shifts in the phonon frequencies in GaN quantum dots; models and measurements of confinement-induced shifts in the phonon frequencies in GaN quantum dots; the characterization of quantum dots in chemically-assembled optoelectronic structures; formulating a theory of the spontaneous polarization of the nanoscale würtzite structures; formulating models for conductance in nanowires components for optoelectronic devices and systems; and designing photodetectors using würtzite-based quantum dots.

## (5) List of Publications and Technical Reports

### PAPERS PUBLISHED

- Jianyong Yang, Gail J. Brown, Mitra Dutta, and Michael A. Stroscio, "Photon Absorption in the Reststrahlen Band of Thin Films of GaN and AlN: Two Phonon Effects, Journal of Applied Physics, 89, 043517, (2005).



- Mitra Dutta, Gail J. Brown, Dinakar Ramadurai, Dwarakanath Geerpuram, Jianyong Yang, Babak Kohanpour, Chen Chen, and Michael A. Stroscio, "Carrier Scattering by Optical Phonons, Two-Phonon Processes in Photon Absorption, and Spontaneous Polarization in Wurtzites," Proceedings of the International Conference on Nonequilibrium Processes in Semiconductors, Springer Publishing Co., 110, 59-62 (2006); ISBN 10 3 540 36587 7
- Amit Raichura, M. Dutta, and M. A. Stroscio, "Phonon Effects in Nanotubes: Phase-Space Reductions and Electron Conductance," Proceedings of the International Conference on Hot Carriers in Semiconductors, Proceedings of the International Conference on Hot Carriers in Semiconductors, in Nonequilibrium Carrier Dynamics in Semiconductors, Springer Proceedings 110, 187-190 (2006); ISBN 10 3 540 36587 7
- Xin Zheng, Wanqiang Chen, Leonard F. Register, and Michael Stroscio, "Interwell Transport and Scattering in Mono-polar Lasers," B73, 245304 (2006).
- Takayuki Yamanaka, Dimitri Alexson, Mitra Dutta, Michael A. Stroscio, Jay Brown, Pierre Petroff, and James Speck, GaN Quantum Dots: Nanophotonics and Nanophononics, Proceedings SPIE, Vol. 6127 Quantum Sensing and Nanophotonic Devices III, 111-122, (2006).
- Dinakar Ramadurai, Yang Li, Takayuki Yamanaka, Dwarakanath Geerpuram, Viswanath Sankar, Milana Vasudev, Dimitri Alexson, Peng Shi, Mitra Dutta, and Michael A. Stroscio, Tijana Rajh, Zoran Saponjic, Nicholas Kotov and Zhiyong Tang, and Song Xu, Colloidal Quantum Dots as Optoelectronic Elements, Proceedings SPIE, Vol. 6127 Quantum Sensing and Nanophotonic Devices III, 131-143, (2006).
- Mitra Dutta, Michael A. Stroscio, and Bruce J. West, Mechanism for Blinking of Colloidal Semiconductor Quantum Dots in Electrolytic Suspension, Journal of Nanoelectronics and Optoelectronics, 1, 99-103 (2006).
- Dinakar Ramadurai, Dwarakanath Geerpuram, Dimitri Alexson, Mitra Dutta, Nicholas A. Kotov, Zhiyong Tang, and Michael A. Stroscio, Electrical and Optical Properties of Colloidal Semiconductor Nanocrystals in Aqueous Environments, Superlattices and Microstructures, 40, 38-44 (2006).
- M. A. Stroscio, M. Dutta, and Amit Raichura, "Conductance of Nanowires," J. of Computational Electronics, 6, 247-249 (2007).
- T. Yamanaka, M. Dutta, and M. A. Stroscio, "Spontaneous Polarization Effects in Nanoscale Wurtzite Structures," J. of Computational Electronics, 6, 313-316 (2007).
- M. Dutta, M. A. Stroscio, M. Vasudev, D. Ramadurai, L. Torres, and B. West, "Blinking of Colloidal Semiconductor Quantum Dots: Blinking Mechanisms," J. of Computational Electronics, 6, 301-304 (2007).
- Milana Vasudev, Takayuki Yamanaka, Ke Sun, Yang Li, Jianyong Yang, Dinakar Ramadurai, Michael A. Stroscio, and Mitra Dutta, "Colloidal Quantum Dots as Optoelectronic Elements," in Quantum Sensing and Nanophotonic Devices IV, edited by Manijeh Razeghi and Gail J. Brown, SPIE Vol. 6479, 64790I-1-12 (2007).
- Takayuki Yamanaka, Ke Sun, Yang Li, Mitra Dutta, and Michael A. Stroscio, "Spontaneous Polarizations, Electrical Properties, and Phononic Properties of GaN Nanostructures and Systems," in GaN Materials and Devices II, edited by Hadis Morkoc and Cole W. Litton, SPIE Vol. 6473, 64730F-1-14 (2007).
- Mitra Dutta, Michael A. Stroscio, Sicheng Liao, Milana Vasudev, Takayuki Yamanaka, "Blinking Mechanism of Colloidal Semiconductor Quantum Dots: Role of Fluctuating Double Layer Potential," ECS Transactions, 6(2) 547-553 (2007).
- Yang Li, Milana Vasudev, Ke Sun, Mitra Dutta<sup>a</sup>, and Michael A. Stroscio, "Electronic Properties of Organic-inorganic Hybrid Systems," ECS Transactions, 6(2) 297-303 (2007).

- Jianyong Yang, Takayuki Yamanaka, Ke Sun, Milana Vasudev, Yang Li, Michael A. Stroscio, and Mitra Dutta, "Optoelectronic Properties for ZnO and Related Semiconductors in Various Nanoscale Geometries," ECS Transactions, 6(2) 149-160 (2007).
- Takayuki Yamanaka, Milana Vasudev, Mitra Dutta, and Michael A. Stroscio, "Charge Transport Analysis in DNA from the Aspect of Phonon Scattering," ECS Transactions, Vol. 6, (15) 45 (2007).
- Ke Sun, Yang Li, Michael A. Stroscio and Mitra Dutta, "Miniband Formation in Superlattices of Colloidal Quantum Dots and Conductive Polymers," ECS Transactions, Volume 6 (23), "Sensors Based on Nanotechnology 3", 1 (2008).

#### PAPERS IN PRESS

- Sicheng Liao, Mitra Dutta, Dan Schonfeld, Takayuki Yamanaka, and Michael A. Stroscio, "Quantum Dot Blinking: Physical Limit for Nanoscale Optoelectronic Device," Journal of Computational Electronics, in press (2008).
- Mitra Dutta, Ke Sun, Yang Li, Vaishnavi Narayanamurthy, Kitt Reinhardt, and Michael A. Stroscio, Colloidal Quantum Dots (QDs) in Optoelectronic Devices --- Solar Cells, Photodetectors, Light-emitting Diodes, in Handbook for Self-Assembled Semiconductor Nanostructures for Novel Devices in Photonics and Electronics, edited by M. Henini, Elsevier Publ. (in press 2008).

#### PRESENTATIONS

- Mitra Dutta, Gail J. Brown, Dinakar Ramadurai, Dwarakanath Geerpuram, Jianyong Yang, Babak Kohanpour, Chen Chen, and Michael A. Stroscio, "Carrier Scattering by Optical Phonons, Two-Phonon Processes in Photon Absorption, and Spontaneous Polarization in Wurtzites," International Conference on Nonequilibrium Processes in Semiconductors, Chicago, Illinois, August 2005.
- Mitra Dutta, Takayuki Yamanaka, Dimitri Alexson, Jay Brown, Pierre Petroff, James Speck, and Michael A. Stroscio, GaN Quantum Dots: Nanophotonics and Nanophononics SPIE 2006 Optoelectronic Conference, SPIE Opto 2006, Quantum Sensing and Nanophotonic Devices III, Los Angeles, January 2006. (INVITED)
- Michael A. Stroscio, Dinakar Ramadurai, Yang Li, Takayuki Yamanaka, Dimitri Alexson, Mitra Dutta, Dwarakanath Geerpuram, Tijana Rajh, Nicholas Kotov, Peng Shi, Zhiyong Tang, Milana Vasudev, and Sankar Viswanath, "Colloidal Quantum Dots as Optoelectronic Elements SPIE 2006 Optoelectronics Conference, SPIE Opto 2006, Quantum Sensing and Nanophotonic Devices III, Los Angeles, January 2006. (INVITED)
- Mitra Dutta, Takayuki Yamanaka, Dimitri Alexson, Jay Brown, Pierre Petroff, James Speck, and Michael A. Stroscio, GaN Quantum Dots: Nanophotonics and Nanophononics, SPIE 2006 Optoelectronic Conference, SPIE Opto 2006, Quantum Sensing and Nanophotonic Devices III, Los Angeles, January 2006. (INVITED)
- Michael A. Stroscio and Mitra Dutta, Phonon Engineering in Nanoscale Structures: Advanced Electronic and Optoelectronic Applications, DARPA Workshop on Nanoscopic Optical Phonon Engineering, December 2005.

Invited Speaker, DARPA Workshop on Nanoscopic Optical Phonon Engineering, Arlington, VA, December 2005.



- Michael A. Stroschio and Mitra Dutta, "Leadership in Interdisciplinary University Research on High Frequency Microelectronics and Carrier-Phonons Interactions in Semiconductor Nanostructures: Pioneering Contributions at the University of Michigan," High Frequency Microelectronics Symposium, September 30, 2005. (Invited Keynote)
- Michael A. Stroschio and Mitra Dutta, "Phonon Lifetimes and Phonon Confinement Effects in Semiconductor Heterostructures: Central Role of the Klemens Channel," Symposium in Honor of Paul Klemens as part of World Year of Physics/Einstein Centennial Lecture Series, University of Connecticut, Storrs, CT, October 21, 2005. (Invited) Other invited speakers in the Lecture Series were Randy Hulet, Ron Mallett, Patricia Rife, Frank Wilczek, Dan Kleppner, Francis Everitt, Alan Guth, Marlan Scully, Georgi Dvali, John Donoghue, and Alain Aspect.
- Amit Raichura, M. Dutta, and M. A. Stroschio, "Conductance of Nanowires," International Workshop on Computational Electronics (IWCE), Vienna, May 25-27, 2006; in Proceedings of 11<sup>th</sup> IWCE, eds. Hans Kosina and Siegfried Selberherr, Technical University-Wien, ISBN 3-901578-16-1.
- T. Yamanaka, M. Dutta, and M. A. Stroschio, "Spontaneous Polarization Effects in Nanoscale Wurtzite Structures," International Workshop on Computational Electronics (IWCE), Vienna, May 25-27, 2006; in Proceedings of 11<sup>th</sup> IWCE, eds. Hans Kosina and Siegfried Selberherr, Technical University-Wien, ISBN 3-901578-16-1.
- Michael A. Stroschio and Mitra Dutta, Phonon Engineering in Nanoscale Structures: Advanced Electronic and Optoelectronic Applications, DARPA Workshop on Nanoscopic Optical Phonon Engineering, December 2005.
- Milana Vasudev, Takayuki Yamanaka, Ke Sun, Yang Li, Jianyong Yang, Dinakar Ramadurai, Michael A. Stroschio, and Mitra Dutta, "Colloidal Quantum Dots as Optoelectronic Elements," SPIE Conference 6479, Quantum Sensing and Nanophotonic Devices IV, Conference Chairs - Manijeh Razeghi and Gail J. Brown, San Jose, CA, January 23, 2007.
- Takayuki Yamanaka, Ke Sun, Yang Li, Mitra Dutta, and Michael A. Stroschio, "Spontaneous Polarizations, Electrical Properties, and Phononic Properties of GaN Nanostructures and Systems," SPIE Conference 6473, GaN Materials and Devices II, Conference Chairs - Hadis Morkoc and Cole W. Litton, San Jose, CA, January 22, 2007.
- Mitra Dutta, Michael A. Stroschio, Sicheng Liao, Milana Vasudev, Takayuki Yamanaka, Blinking Mechanism of Colloidal Semiconductor Quantum Dots: Role of Fluctuating Double Layer Potential, Abstract Submitted to the 211<sup>th</sup> ECS Meeting, Chicago, May 6-11, 2007.
- Yang Li, Milana Vasudev, Ke Sun, Mitra Dutta<sup>a</sup>, and Michael A. Stroschio, Electronic Properties of Organic-inorganic Hybrid Systems, Abstract Submitted to the 211<sup>th</sup> ECS Meeting, Chicago, May 6-11, 2007.
- Jianyong Yang, Takayuki Yamanaka, Ke Sun, Milana Vasudev, Yang Li, Michael A. Stroschio, and Mitra Dutta, "Optoelectronic Properties for ZnO and Related Semiconductors in Various Nanoscale Geometries" Abstract Submitted to the 211<sup>th</sup> ECS Meeting, Chicago, May 6-11, 2007.
- Milana Vasudev, Takayuki Yamanaka, Mitra Dutta, and Michael A. Stroschio, "Integrated DNA-Nanoparticle Complexes: Synthesis, Electrical and Optical Properties," Abstract Submitted to the 211<sup>th</sup> ECS Meeting, Chicago, May 6-11, 2007.
- Takayuki Yamanaka, Milana Vasudev, Mitra Dutta, and Michael A. Stroschio, "Charge Transport Analysis in DNA from the Aspect of Phonon Scattering," ECS Meeting, Chicago, May 6-11, 2007.
- Ke Sun, Yang Li, Michael A. Stroschio and Mitra Dutta, "Miniband Formation in Superlattices of Colloidal Quantum Dots and Conductive Polymers," ECS Meeting, Chicago, May 6-11, 2007.

- Mitra Dutta and Michael A. Stroscio, "Confinement in Nanoscale Semiconductor Structures," Phonons 2007, Paris, July 15-18, 2007. (Invited)
- Mitra Dutta, Dan Schonfeld, Sicheng Liao and Michael A. Stroscio, "Quantum Dot Blinking: Physical Limit for Nanoscale Optoelectronic Device," 12th International Workshop on Computational Electronics, Amherst, MA, October 2007.
- Sicheng Liao, Mitra Dutta, Dan Schonfeld, Takayuki Yamanaka, and Michael A. Stroscio, "Quantum Dot Blinking: Physical Limit for Nanoscale Optoelectronic Device," 12th International Workshop on Computational Electronics, Amherst, MA, October 2007.
- Ke Sun, Mitra Dutta, and Michael A. Stroscio, Transmission Coefficients for Minibands Formed in Quantum Dot Arrays under Bias, 12th International Workshop on Computational Electronics, Amherst, MA, October 2007.
- Takayuki Yamanaka, Mitra Dutta, and Michael A. Stroscio, "Simulation of Charge Transport in DNA," International Conference on Hot Carriers in Semiconductors, Japan, August (2007).
- Michael A. Stroscio, Mitra Dutta, Takayuki Yamanaka, Jianyong Yang, and Chen Chen, Challenges Facing GaN and ZnO: Frohlich Interaction and Spontaneous Polarization, at Workshop on Challenges Facing GaN and ZnO, hosted by Virginia Commonwealth University, Richmond, VA, 18-19 Oct 2007. (Invited)
- Michael A. Stroscio, Mitra Dutta, Sun Ke, Milana Vasudev, Hye-Son Jung, Jianyong Yang, Yang Li, Ayan Kar, Donna Wu, Sicheng Liao, "Semiconductor Nanostructures: Interdisciplinary Applications," at Interdisciplinary Science & Engineering Materials Research Group Workshop (ISEMRG Workshop), Chicago, 16-17 April 2008.
- Sun Ke, Milana Vasudev, Hye-Son Jung, Jianyong Yang, Yang Li, Kitt Reinhardt, Michael A. Stroscio, and Mitra Dutta, "Applications of Colloidal Quantum Dots," Workshop on Recent Advances on Low Dimensional Structures, University of Nottingham, England, April 7-9, 2008. (Invited)
- Michael A. Stroscio, and Mitra Dutta, "Quantum Engineering of Nanostructures for Optoelectronic Device Applications: Optimizing Device Performance," AFOSR Nanotechnology Review, Dayton, OH, May 5-7, 2008.

#### (6) List of All Participating Scientific Personnel

Michael A. Stroscio, PI

Mitra Dutta, Co-PI

Ke Sun

Takayuki Yamanaka; received PhD, now at Northwestern University. Thesis results are all described in published articles listed previously.

Amit Raichura

#### (7) Honors and Awards

The PI was:

named the Richard and Loan Hill Professor in September 2006;

selected for the Technical Leadership Award for the Nano-DDS Conference in July 2008;

appointed to the Editorial Board of the IEEE Proceedings in Fall 2007;

appointed as a member of the National Research Council (NRC) Board on Army Science and Technology (BAST) in January 2008.

(8) Report of Inventions: None